Shotcrete Retrofit of a Mechanically Stabilized Earth Wall

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The Municipality of Maple Ridge in British Columbia, Canada, commissioned a specialty contractor to build a 9 m (29.5 ft) diameter culvert, incorporated in a mechanically stabilized earth (MSE) wall, to provide a street crossing for a stream. The culvert had been partly sunk into the stream bed to adapt to the site conditions. The MSE walls were a maximum 8 m (26.3 ft) high above the ground and 70 m (230 ft) long. Figure 1 shows part of the North Face of the MSE wall.

The fill used in the construction of the MSE wall contained a fraction of fine dredged river sand. After construction, fine particles of the sand dried out and started to migrate through the galvanized metal screen that comprised part of the MSE wall. This resulted in voids at the surface of the MSE walls. The voids were a concern as they constituted a potential cause for future settlement of the sidewalks and asphalt pavement constructed between the MSE walls. The specialty contractor decided to remedy this situation by arresting the migrating fill before it came to its natural equilibrium, by refilling the surface voids and applying a shotcrete lining.

REPAIR SPECIFICATION

The design engineer recommended filling the voids with shotcrete and stabilizing the surface of the MSE walls with a permanent shotcrete lining. The specifications called for the following procedures:

- remove the galvanized metal screen from voided areas
- clean the galvanized steel reinforcement grid on the surface of the MSE walls
- fill the voids with shotcrete
- build a shotcrete surface lining of nominally 70 mm (2.75 in.) thickness over the entire MSE wall areas
- mist and fog any fresh shotcrete if the ambient conditions resulted in surface evaporation rates exceeding 0.2 kg/m^2/h (0.04 lb/ft^2/h)
- moist cure the hardened shotcrete for 7 days to minimize restrained shrinkage cracking.

The engineer provided prescription shotcrete mix designs for both the wet- and dry-mix shotcrete processes. In both cases, the basic mix proportions were:

Material	Addition rate, kg/m^3 (lbs/yd^3)
Cement	380 (640)
Fly ash	30 (50)
Silica fume	50 (84)
Water	180 (303)
Aggregate	1720 (2900)

Should wet-mix shotcrete be used, the addition of a water-reducing admixture to produce an as-batched slump of 50 ± 20 mm (2 in. ± 0.8 in.), and an air-entraining admixture to provide an as-batched air content of 8 ± 2% were required.

All parties involved in the project were particularly concerned about protecting the fish-bearing stream running through the culvert. Erosion products and contamination with alkaline shotcrete rebound, waste or curing water run-off were unacceptable. The consultant required extensive protective measures to be implemented. Only suitably qualified selected contractors were invited to submit bids.

ALTERNATIVE PROPOSAL

The tender documents allowed for value engineering alternatives. One contractor submitted a value engineering alternative in his bid. Instead of cutting out the galvanized steel screen at locations of voids, and applying dental shotcrete, he decided to leave the screen in place and refill the voids with sand, followed by lining the MSE walls with shotcrete as specified in the tender. This contractor proposed using masonry sand, and ordinary dry-mix shotcrete equipment to spray the sand through the 6 mm (0.25 in.) wide openings of the galvanized metal screen covering the MSE walls, instead of removing the screen and filling the voids with dental shotcrete. The alternative proposal resulted in a cost savings of approximately 10% over the cost of the works stipulated by the tender document. After discussions between the contractor, the owner, and the engineer, all parties agreed that the alternative bid had good potential to succeed, and the contractor was awarded the work based on his alternative proposal, subject to him demonstrating that the proposed spraying of sand through the screen would fill the voids satisfactorily.

Figure 1. North face of MSE wall before repairs.

Figure 2. Section of north face after filling voids with sand.

EXECUTION

After securing the construction site against erosion and accidental contamination of the stream, the Contractor conducted trials to optimize the sand spraying technique. He used a Meyco GM 60 rotor gun with premoisturizer, and a rubber hose with 50 mm (2 in.) internal diameter, connected to a plastic nozzle. The longest conveying distance for the sand was approximately 80 m (263 ft.). After determining the optimum sand moisture content, air flow, and nozzle position, the contractor proceeded to shoot masonry sand through the galvanized metal screen and successfully fill the surface voids in the MSE walls. The sand rebound was surprisingly low. Overall, it was estimated to be about 20%. No significant short-term migration of the fines through the screen occurred, so that the final shotcrete lining could be applied as late as a day after spraying the damp sand. Figure 2 shows part of the north face of the MSE wall after the voids had been filled with sand. Figure 3 shows a sand-filled void in greater detail.

After filling the voids in a given wall section with sand, the contractor then cleaned the reinforcing grid on the MSE walls with pressurized air to remove any sand accumulation around the steel reinforcement grid, and shot a nominally 70 mm (2.75 in.) thick shotcrete lining, using the wet-mix shotcrete process. Ready-mix shotcrete was delivered to the site. The shotcrete surface was left in its natural, as-shot finish.

During the application of the shotcrete, the engineer periodically monitored the evaporation conditions on site. The ambient weather conditions were favorable at all times, so the specified special curing measures for high-evaporation conditions were not required. However, had the ambient evaporation rate exceeded 0.2 $kg/m^3/h$ (0.04 $lb/ft^2/h$), the contractor would have used a pressure washer with an atomizing nozzle to fog and mist any fresh shotcrete until it set, followed by curing with wet burlap and polyethylene sheets.

After freshly applied shotcrete had hardened, the contractor sprayed it with water and covered it with polyethylene sheets to prevent rapid evaporation. In the following 3 to 5 days, the contractor periodically lifted the polyethylene sheets, sprayed the concrete with water, and covered the

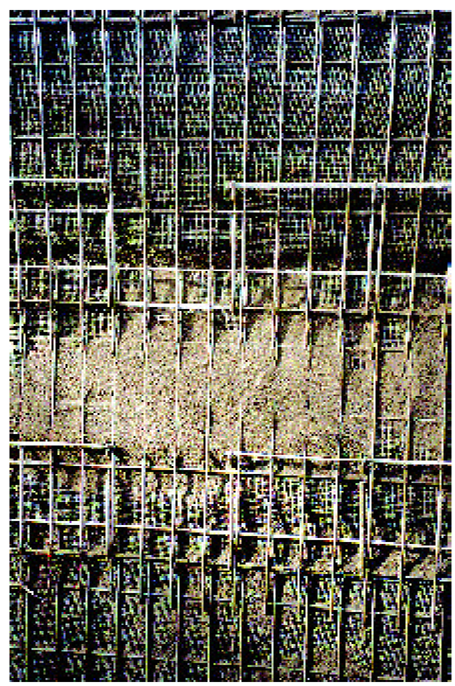

Figure 3. Detail of a void filled with sand through the steel screen.

Figure 4. North face after application of shotcrete lining.

shotcrete again. Care was taken to prevent the shotcrete surface from completely drying out, though at times only limited free moisture remained before the surface was remoisturized. Figure 4 shows the north wall after completion of the shotcrete lining.

RESULTS

The project was finished within the allotted time frame and below budget, to the satisfaction of the owner and the engineer. The stream had been protected from any contamination with shotcreting or other construction materials. The natural gun finish of the shotcrete walls is considered esthetically acceptable. Some vertical restrained shrinkage cracks opened in the south wall–they were not unexpected. However, since the cracks are a maximum 0.3 mm (0.012 in.) wide and the reinforcement of the MSE wall surface is galvanized steel designed to be exposed to ambient weather conditions without any protection, these cracks are considered acceptable for this particular project. Furthermore, some self-healing of the cracks has already been observed after about 1 month in service.

The shotcrete itself is of excellent quality. The engineer tested core specimens extracted from test panels for compressive strength, and for boiled absorption and volume of permeable voids. The core compressive strengths were approximately 40 MPa (5800 psi) at 7 days, 50 MPa (7250 psi) at 28 days, and 60 MPa (8700 psi) at 56 days. The tender documents described the prescription mix as having a nominally 35 MPa (5075 psi) compressive strength at 28 days. The average boiled absorption of the shotcrete test specimens was 5.5%, and the average volume of permeable voids was 12.0%. By comparison, the specification stipulated maxima of 8% for the boiled absorption, and 17% for the volume of permeable voids. Maxima for shotcrete considered as having excellent durability characteristics are 6% and 14%, respectively.

In summary, the use of a dry-mix shotcrete gun to spray a fine sand back through the galvanized metal screen to fill voids, and application of a wet-mix shotcrete lining resulted in a successful retrofit of a mechanically stabilized earth wall.

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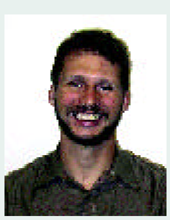

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